Are the Neoproterozoic Lamil and Throssell Groups of the Paterson Orogen allochthonous?

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Abstract

Neoproterozoic (c. 1070–680 Ma) metasedimentary formations of the Lamil and Throssell Groups of the Paterson Orogen have detrital zircon age populations that are compatible with a principal source from the Mesoproterozoic Musgrave Complex, 400 km to the southeast. A subordinate source is Palaeoproterozoic rocks of the underlying Rudall Complex or the Arunta Orogen 400 km to the east. However, predominantly northeastward trending palaeocurrents in the Lamil and Throssell Groups suggest that their source was from the southwest, a region now occupied by the Archaean Pilbara Craton. This apparent contradiction may be explained if these groups and the underlying crystalline Rudall Complex have an allochthonous relationship to the Pilbara Craton. The Rudall Complex may be a western extension of the Arunta Orogen that has been displaced by at least 400 km, from central Australia to its present position, along a series of faults that extend from the Vines–Southwest–McKay Faults to the northern margin of the Amadeus Basin. This displacement followed deposition of the Lamil and Throssell Groups, probably during the c. 550 Ma Paterson Orogeny. These groups may be part of the Neoproterozoic Amadeus Basin, thus enhancing its prospectivity for Telfer-style gold and base metal mineralization.

KEYWORDS: Neoproterozoic, Officer Basin, Amadeus Basin, Lamil Group, Throssell Group, Inindia beds, tectonics, zircon dating.

Regional setting

The Palaeoproterozoic to Neoproterozoic Paterson Orogen is delineated by an arcuate series of gravity highs traditionally known as the Warri Gravity Ridge (Iasky, 1990), which, although less than 100 km wide, extends about 2000 km from the east Pilbara region to central Australia (Fig. 1). Rocks of the orogen are exposed in the northwest along the eastern margin of the Archaean Pilbara Craton, and about 400 km to the southeast within the Musgrave Complex and along the northern margin of the Gawler Craton (Fig. 2). The late Neoproterozoic Paterson Orogeny (probably equivalent to the c. 550 Ma Petermann Orogeny in the Musgrave Complex) deformed the orogen into its present 'z'-shaped configuration by displacement along a major fault zone that extends eastwards towards the northern margin of the Amadeus Basin (Fig. 1).

During the intracratonic Petermann Orogeny in central Australia, Mesoproterozoic (c. 1180 Ma) granulite- and amphibolite-facies gneisses in the Musgrave Complex were heterogeneously overprinted by easterly trending shear zones that formed under eclogite- to greenschist-facies conditions (Camacho et al., 1997). These high-strain shear zones have both strike-slip and reverse movements and may have formed part of a strike-slip-related, crustal-scale, flower-type structure (Camacho and McDougall, 2000). Such structures can account for the burial and subsequent exhumation of approximately 23 km of the granulite-facies gneisses during the Petermann Orogeny within an interval of about 15 m.y. (Camacho and McDougall, 2000).

The Paterson and Petermann Orogenies were active during a period of global plate reorganization, commonly known as the Panafrican event, involving the initiation of subduction and convergent plate-margin activity during a late phase in the breakup of Rodinia (Cawood and Leitch, 2001). This locally involved transpressional, tensional or transtensional and major strike-slip deformation. During this phase of the breakup, the extension direction was orientated northeast–southwest along the Tasman line, which is the boundary between the Precambrian Mount Isa and Broken Hill Orogens to the west and the Phanerozoic Lachlan and Thomson Fold Belts to the east.

The northwesternmost part of the Paterson Orogen has been subdivided into the Palaeo-proterozoic to Mesoproterozoic Rudall Complex basement and Neoproterozoic sedimentary cover rocks. The latter succession has been

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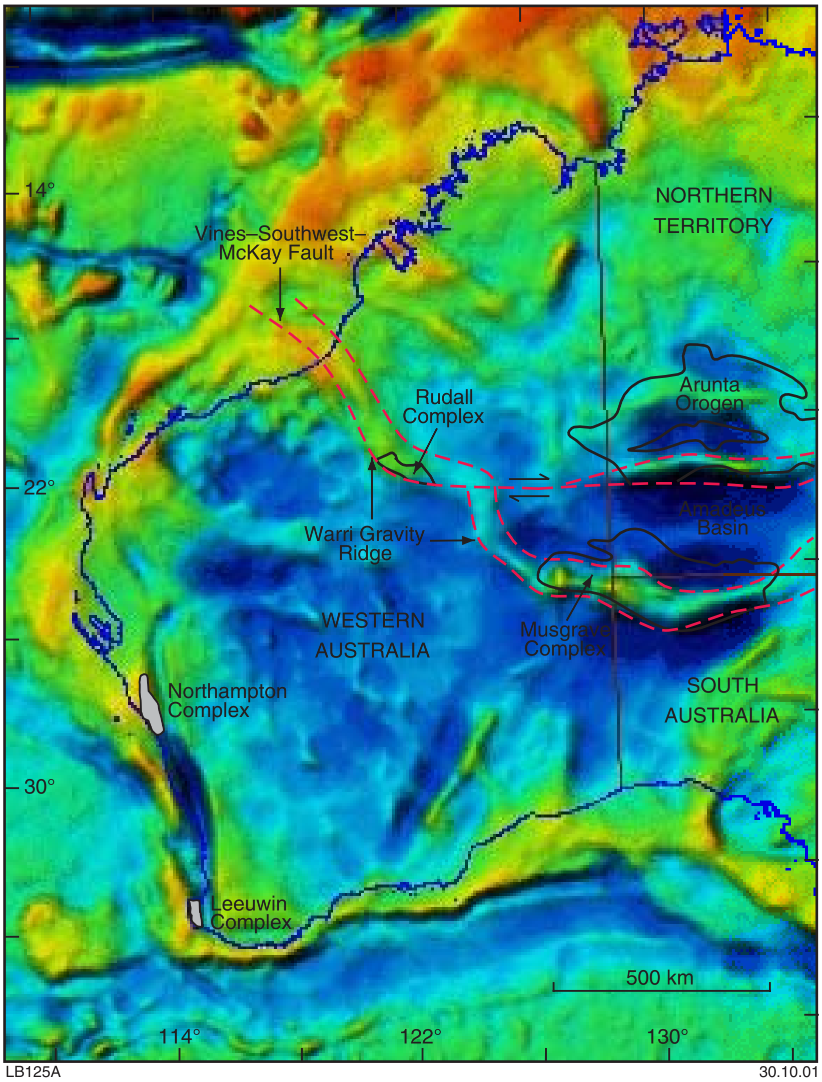

Figure 1. Gravity anomaly map of central and Western Australia (Murray et al., 1997) showing the location of the Warri Gravity Ridge, which approximately outlines the Paterson Orogen

further divided into the Tarcunyah, Throssell, and Lamil Groups (Bagas et al., 1995).

The exposed contact between the Tarcunyah and Throssell Groups is marked by the Vines, Southwest, and McKay Faults, which extend over a distance of 400 km (Fig. 2). These faults are long-lived structures that were last reactivated during the Paterson Orogeny (Williams and Bagas, 1999), and coincide with the southwestern margin of the northern part of the Warri Gravity Ridge (Fig. 1). The faults have both strike-slip and reverse components of movement (Bagas and Smithies, 1998; Hickman and Bagas, 1998; Williams and Bagas, 1999).

On the basis of gravity data, the Throssell and Lamil Groups were juxtaposed along a major concealed northwest-trending fault, which is probably an extension of the long-lived Camel–Tabletop Fault Zone that was also active during the c. 550 Ma Paterson Orogeny (Bagas and Smithies, 1998).

In this paper we constrain the age and provenance of the cover sequences in the northwestern Paterson Orogen to the Neoproterozoic, using sensitive high-resolution ion microprobe (SHRIMP) U–Pb detrital-zircon age distributions, and show that they were not sourced from the neighbouring Archaean terranes.

Cover sequences in the Paterson Orogen

Williams (1990) defined the 'Yeneena Group' as including three geographically separated packages of fluvial–marine sedimentary rocks. These packages have been given 'group' status and, from east to west, are named the Tarcunyah, Throssell, and Lamil Groups (Williams and Bagas, 1999). The 'Yeneena Group' was accordingly redefined as the Yeneena Supergroup to include the Throssell and Lamil Groups, and the Tarcunyah Group was included in the northwestern Officer Basin (Bagas et al., 1995).

Conglomerate, sandstone, siltstone, carbonate, and evaporites of the Tarcunyah Group unconformably overlie the Archaean Pilbara Craton and Mesoproterozoic Bangemall Supergroup (Williams and Trendall, 1998; Fig. 3). Grey and Stevens (1997) and Stevens and Grey (1997) correlated stromatolite and acritarch fossils in the Tarcunyah Group at the base of the northwestern Officer Basin (Bagas et al., 1995) with fossils from Supersequence 1 of the Centralian Superbasin (Walter et al., 1995). Grey and Stevens (1997) identified palynomorph taxa in the Tarcunyah Group, including *Leiosphaeridia* sp., *Synsphaeridium* sp., *Arctucellularia ellipsoidea*, and *Satka* sp. The stromatolites belong to the *Acaciella australica* Stromatolite Assemblage of Grey and Stevens (1997).

The Throssell Group is a sandstone–shale–carbonate succession that unconformably overlies and is locally faulted against the Rudall Complex (Fig. 2). The group is interpreted, on sedimentological grounds, to have been deposited in a shallow-water fluviatile to marine-shelf environment (Bagas and Smithies, 1998; Hickman and Bagas, 1999), probably within a strike-slip basin during the onset of northeast–southwest convergence during the Miles Orogeny (Hickman and Bagas, 1998). No diagnostic stromatolite or acritarch fossils have been identified in the group.

The Lamil Group consists of sandstone, siltstone, and carbonate of the Malu, Puntapunta, and Wilki Formations (Fig. 3; Bagas, 2000). No stromatolite or acritarch fossils have been found in the Lamil Group.

Turner (1982) proposed an intracratonic basin setting for the deposition of the Lamil Group and suggested that deposition occurred at a continental margin or within a failed rift. On the basis of a structural study around the Telfer gold mine (Fig. 2), Harris (1985) suggested that the Lamil Group was deposited in a pull-apart basin developed in an extensional strike-slip system.

Conglomerate, sandstone, shale, and carbonate units exposed just north of the McKay Fault (Fig. 2) were tentatively included in the Throssell Group on the basis of similarities in rock type, structural style, and metamorphic grade (Bagas and Smithies, 1998). However, the stratigraphic position of these units is not clear. Comparisons of detrital zircon age distributions from these units with those of the Coolbro Sandstone (Williams et al., 1976) in the Throssell Group and Malu Formation (Bagas, 2000) in the Lamil Group (Fig. 3) are being undertaken to test these correlations.

Source regions

The precise ages of the Lamil and Throssell Groups are uncertain. Chin and de Laeter (1981) suggested that the former Yeneena Group was deformed at about 1132 ± 21 Ma, which is the Rb–Sr isochron age for pegmatite veining cutting Palaeoproterozoic deformation fabrics in the Rudall Complex. This deformation event has since been referred to as the Miles Orogeny (Bagas and Smithies, 1998).

Exploration programs have since been based on the premise that these rocks are correlatives of the Mesoproterozoic McArthur River Group of northern Australia. Lead-isotope analyses of galena from the Broadhurst Formation of the Throssell Group yielded model-lead ages ranging from c. 940 to 550 Ma (Hickman and Clarke, 1994; Hickman and Bagas, 1998). It was therefore assumed that the Broadhurst Formation must be at least 940 million years old. However, galena lead-model ages are based on the assumption that the isotopic composition of the lead in the galena has evolved along a model ore-growth curve. For ancient rocks (≥3 Ga), deviation

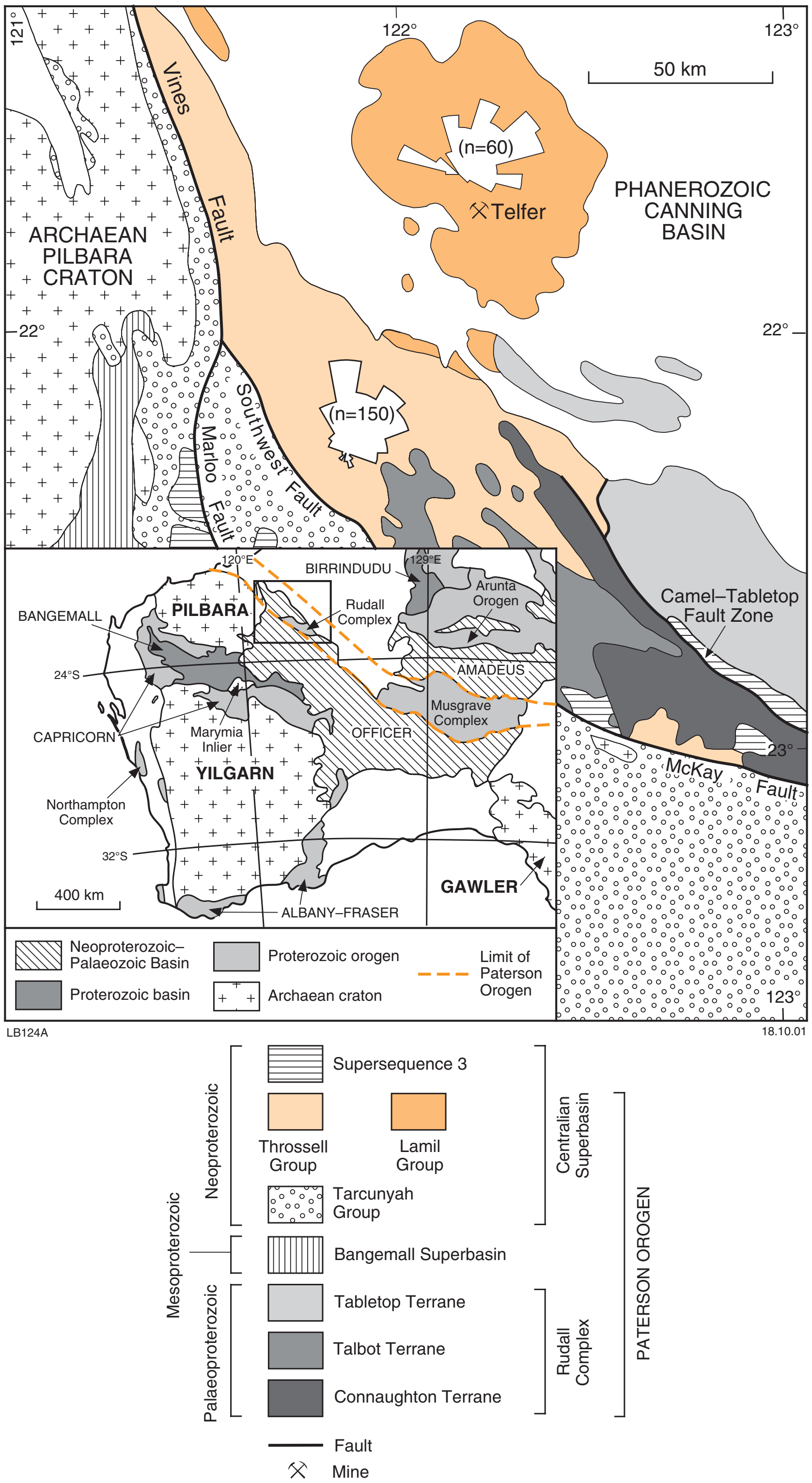

Figure 2. Regional geological setting of the northwestern Paterson Orogen and main tectonic units of central and western Australia. Rose diagrams show palaeocurrent directions for the Lamil and Throssell Groups

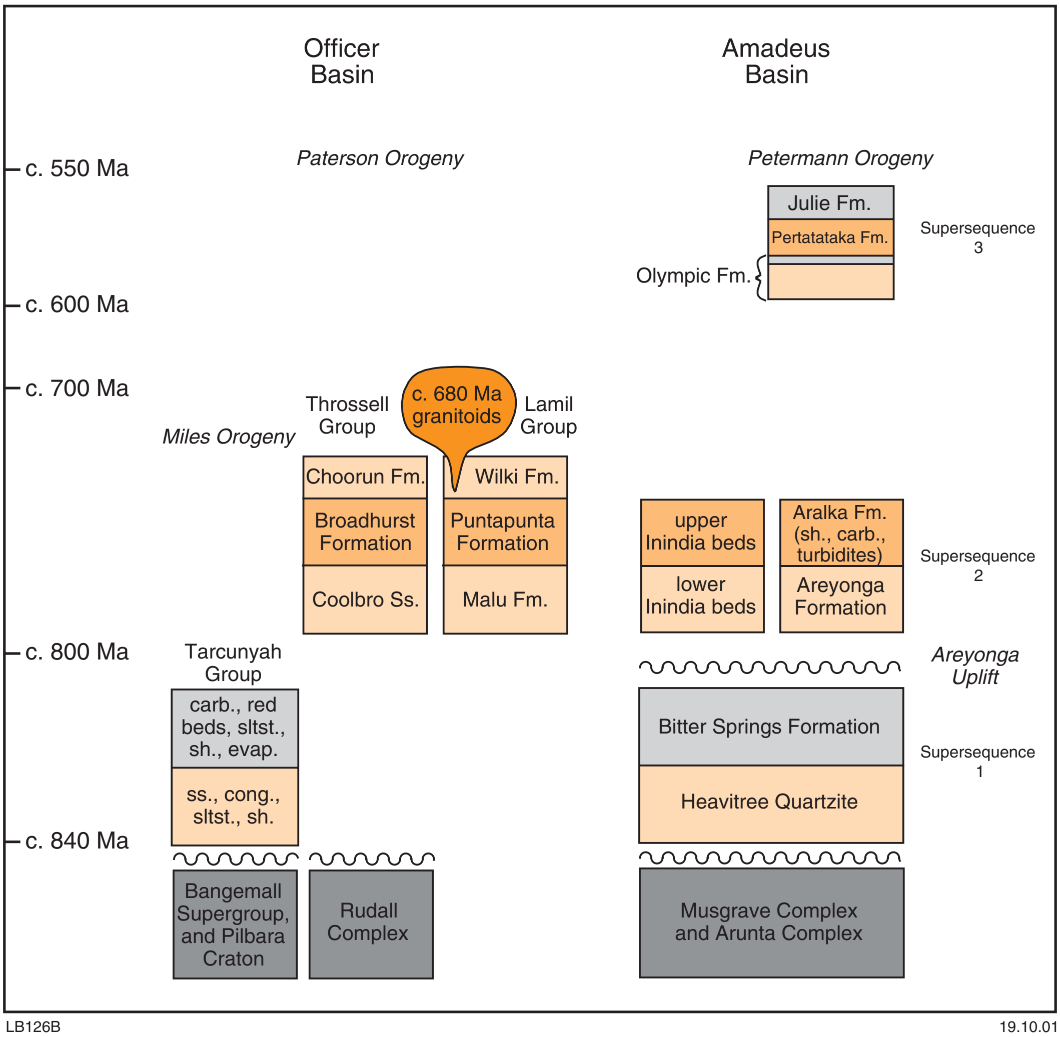

Figure 3. Simplified stratigraphy for the Neoproterozoic sequences of the northwestern Officer Basin, the Throssell and Lamil Groups and the Amadeus Basin (modified after Walter et al., 2000). Abbreviations: carb. = carbonate; cong. = conglomerate; evap. = evaporites; Fm. = Formation; sh. = shale; sltst. = siltstone; ss. = sandstone

from the model ore-growth curve is generally small, but for younger rocks, galena model ages become increasingly unreliable and imprecise. Studies by Anderson (1999) suggested that the lead in the galena from the Broadhurst Formation may have been derived by mixing of primitive and evolved crustal sources. This indicates that model-lead ages determined from the Broadhurst Formation must be regarded as inconclusive.

In an attempt to more accurately determine the depositional age and provenance of the Lamil and Throssell Groups, detrital zircons were analysed from sandstone in the Coolbro Sandstone (GSWA sample 169118) of the Throssell Group, and the Malu Formation of the Lamil Group (GSWA samples 137655 and 137657; Figs 3 and 4).

SHRIMP U–Pb detrital-zircon dates place a maximum depositional age for the Throssell and Lamil Groups at c. 1070 Ma (Fig. 4; Nelson, 2000). Monzogranite and syeno-granite intrusions place a minimum depositional age of c. 678 Ma on the Lamil Group (Dunphy, J., 1999, pers. comm.). Lamil and Throssell Group strata have very similar zircon age distributions (Fig. 4), which suggests the same provenance and possible stratigraphic correlation. Consequently, zircon age distributions collected from these formations have been pooled and compared with those from the Musgrave Complex, the north-western part of the Paterson Orogen, and the Arunta Orogen (Fig. 5).

The zircon ages from the Lamil and Throssell Groups in Figure 5 are most similar to the Musgrave Complex ages. A small number of these zircons have ages that are compatible with derivation from the older Rudall Complex component of the Paterson Orogen and Arunta Orogen. Zircon-bearing rocks of c. 1070 Ma age are known only from the Musgrave Complex (Sun et al., 1996; Camacho et al.,

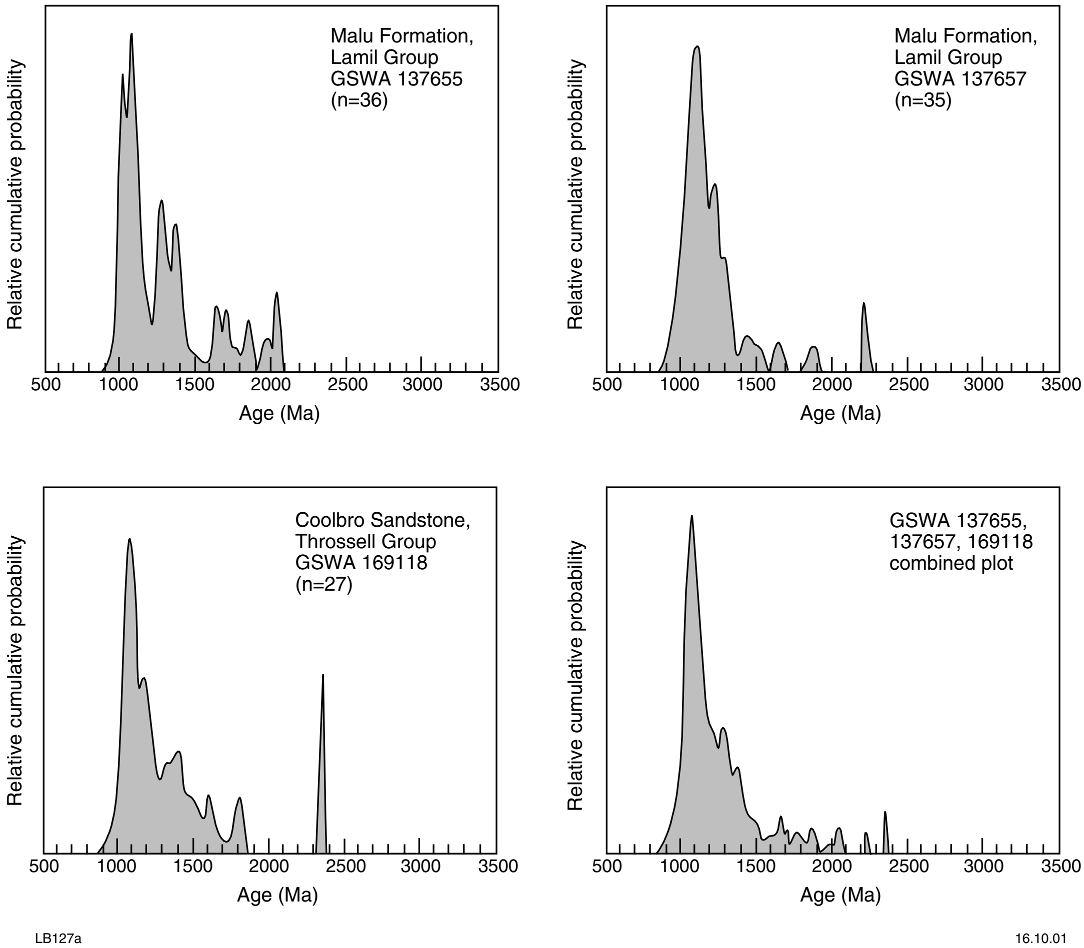

Figure 4. Cumulative probability diagrams of U–Pb SHRIMP ages of detrital zircons in samples GSWA 137655 (n = 36) and 137657 (n = 35) from the Malu Formation (both from MGA Zone 51, 415075E 7597376N) and sample GSWA 169118 (n = 27) from the Coolbro Sandstone (from MGA Zone 51, 414920E 7495289N). Also shown are the pooled detrital zircon components from the Malu Formation and the Coolbro Sandstone

1997; Scrimgeour et al., 1999), the Northampton Complex to the west of the Yilgarn Craton (Bruguier et al., 1999), and the Leeuwin Complex in southwestern Western Australia (Nelson, 1999; Fig. 2).

The Northampton and Leeuwin Complexes are unlikely sources for the Lamil and Throssell Groups, in part because no detrital zircons with ages characteristic of the intervening Yilgarn Craton have been found. In addition, the detrital zircon distribution from the Lamil and Throssell Groups closely resembles that of the lower Inindia beds of the Amadeus Basin (Camacho et al., in prep.; Fig. 6), suggesting a very similar provenance. Walter et al. (2000) included the lower Inindia beds and the Areyonga and Aralka Formations in Supersequence 2 of the Amadeus Basin (Fig. 3).

The lower Inindia beds consist of quartz sandstone, siltstone, and rare dolomite, and overlie a regionally widespread erosional surface on the Bitter Springs Formation. This surface probably represents a depositional hiatus rather than a major deformation event (Lindsay and Korsch, 1991). The lower Inindia beds have been correlated with the tillitic Areyonga Formation in the northern part of the Amadeus Basin (Edgoose et al., 1993). The detrital zircon distributions from the Lamil and Throssell Groups are significantly different to those from units above and below the lower Inindia beds in the Amadeus Basin (Camacho et al., in prep.).

Discussion

The absence of detrital zircons with Archaean ages suggests that the Throssell and Lamil Groups were not derived from the Pilbara and Yilgarn Cratons. In contrast, palaeocurrent data from the Throssell and Lamil Groups (Hickman and Clarke, 1994; Bagas and Nelson, 2001) indicate a source to the southwest, in a region now occupied by the Pilbara Craton (Fig. 2).

There is no evidence that the Pilbara Craton (3600–2400 Ma) was covered by significant thicknesses of Palaeoproterozoic or Mesoproterozoic rocks during the deposition of the Lamil and Throssell Groups, as the sedimentary rocks of the overlying Hamersley Basin are of

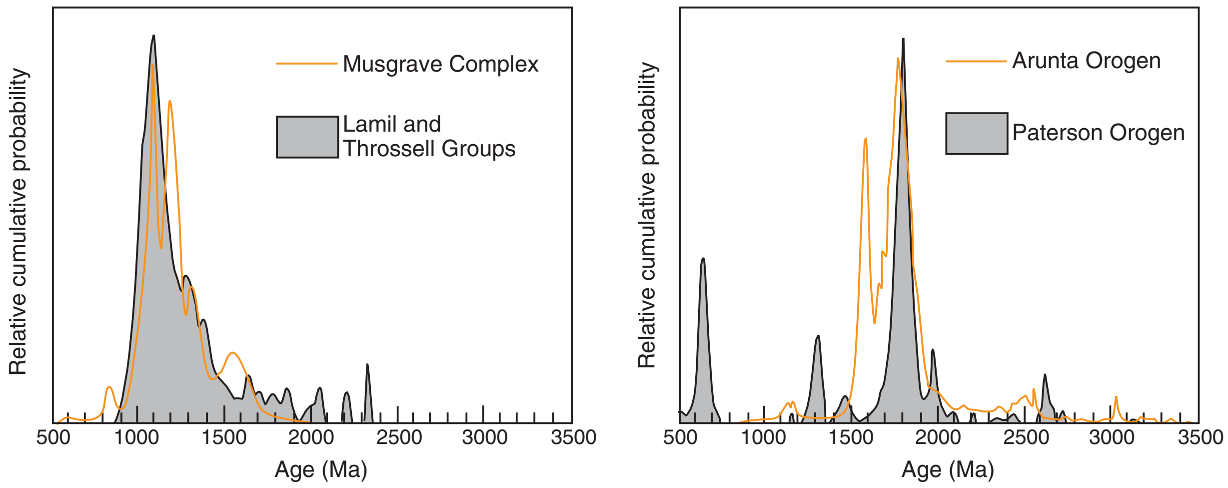

Figure 5. Comparison between relative cumulative probability distributions of pooled detrital zircon components in the Lamil and Throssell Groups and inherited–detrital zircon components of the undifferentiated Paterson Orogen (n = 437; Bagas and Nelson, 2001), Musgrave Complex (n = 1405; Camacho et al., in prep.), and Arunta Orogen (n = 1576; Camacho et al., in prep.)

low metamorphic grade. Furthermore, no felsic, zircon-bearing rocks of c. 1070 Ma age (which is the main zircon population age in the Lamil and Throssell Groups) are known from the Pilbara Craton, Capricorn Orogen, Bangemall Superbasin, or Yilgarn Craton.

The apparent discrepancy between detrital-zircon age populations and palaeocurrent directions can be explained if the Rudall Complex and the younger Throssell and Lamil Groups are considered as a single allochthonous block relative to the Pilbara Craton. The Rudall Complex is interpreted here to represent the western extension of the Arunta Orogen (Fig. 2). The complex was placed into its present relative position by movement of at least 400 km along the Vines–Southwest–McKay fault system in the west and faults along the northern margin of the Amadeus Basin in the east (Fig. 1). Such a large displacement following the deposition of the Lamil and Throssell Groups would have occurred during the c. 550 Ma Paterson Orogeny, which is the youngest recognized orogenic event in the northwestern Paterson Orogen (Hickman and Bagas, 1998). Alternatively, the provenance for both groups could be an unknown area of Mesoproterozoic basement beneath the Officer Basin to the southwest of the Paterson Orogen. Such a provenance, however, would have had to source the same detrital zircon distributions in the lower sandstone units in the Lamil Group, Throssell Group, and the lower Inindia beds.

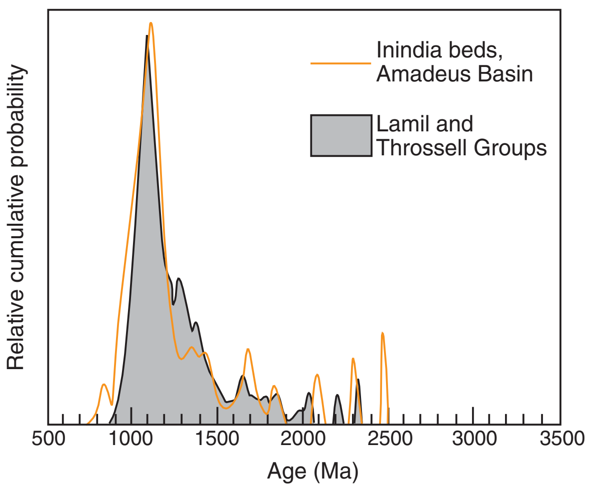

Figure 6. Comparison between relative cumulative probability distributions of pooled detrital-zircon components in the Lamil and Throssell Groups and the lower Inindia beds (n = 50) of the Amadeus Basin (Camacho et al., in prep.)

Further implications of an approximately 400 km displacement of the Rudall Complex and the Lamil and Throssell Groups from central Australia, and the provenance studies using ages for detrital zircons are:

- The Musgrave Complex, Arunta Orogen, and Rudall Complex would have been exposed during the deposition of these groups (and during the deposition of the lower Inindia beds in the Amadeus Basin).
- The Malu Formation of the Lamil Group and the Coolbro Sandstone of the Throssell Group have very similar zircon age populations and may be correlatives.

- The Lamil and Throssell Groups probably correlate with part of Supersequence 2 in the Neoproterozoic Amadeus Basin. This contention is strongly supported by the zircon distributions shown in Figure 6. This has major implications because no Supersequence 2 rocks have been identified in Western Australia until now.
- The term ‘Yeneena Supergroup’ may no longer be valid.
- The poorly exposed and poorly studied Amadeus Basin in eastern Western Australia, between the Musgrave Complex and Arunta Orogen, could be prospective for Telfer-style gold and copper mineralization, particularly if the Amadeus Basin is intruded by c. 680 Ma granitoids. This assumes that the mineralization at Telfer is at least indirectly related to the granitoids intruding the Lamil Group, as suggested by Rowins et al. (1997).

The hypotheses presented above have major implications for the understanding of the Neoproterozoic geology of central and Western Australia and need to be tested by:

- establishing the stratigraphic relationship between the Neoproterozoic Lamil, Throssell, and Tarcunyah Groups, and the lower and upper Inindia beds;
- establishing $\delta^{13}C$ values for carbonates from the Broadhurst and Puntapunta Formations, which could be tested against curves already published;
- testing for anomalously high $\delta^{34}S$ values in shale of the Broadhurst and Puntapunta Formations, because Supersequence 2 is characterized by anomalous high $\delta^{34}S$ values in shale from the Aralka Formation in the Amadeus Basin (Gorjan et al., 2000). This would also provide support for the Supersequence 2 age if the values were similar;
- comparing the detrital-zircon distributions in the lower sandstone units of the Tarcunyah Group with those in the Lamil and Throssell Groups. If they are similar, it may be inferred that sandstone beds of various ages were derived from the same source regions. However, the lack of significant c. 1070 Ma detrital-zircon populations in the Tarcunyah Group would support the suggestion that the Throssell and Lamil Groups are allochthonous relative to the Pilbara Craton. It is anticipated that at least the lower sandstone units in the Tarcunyah Group have an Archaean detrital-zircon population because they unconformably overlie the Pilbara Craton (Williams and Trendall, 1998).

This preliminary work on the Lamil and Throssell Groups shows that a provenance study combining palaeocurrent and detrital-zircon analyses can be a powerful tool in unravelling the geological history of complex structural terranes such as the Paterson Orogen. This signals the possibility of being able to use the age-distribution plots to fingerprint units in structurally complex regions.

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